colleagues[3], this task has become a lot more straightforward. They approach the problem by minimizing a quantity whose value depends on the (infinite) number of possible mathematical descriptions of the noise, the Kraus operators.

This is not a 'magic bullet', as a general prescription for this minimization is still lacking. Nonetheless, to show that the bounds they derive are indeed useful and to give a first taste of the power of their framework, Escher *et al.*[3] provide answers to two very interesting questions. The first refers to the optimal scaling of optical interferometry in the realistic conditions where photons can be absorbed or scattered away. They show that the $1/N$ scaling is attainable only if the number of photons used in the experiment does not exceed a certain threshold, which depends on the intensity of the noise. For a larger number of photons, the quantum advantage consists merely of a constant factor, without any improvement in the scaling, confirming similar recent results[7,8]. The second question on which Escher *et al.* hone their new bounds was already posed in ref. 6, where a procedure that uses non-maximally entangled states was shown to be more robust to noise than the maximally entangled one. It was asked whether this is the optimal procedure — now we know it is. The reduction of the amount of entanglement is a typical trick used to increase the robustness of quantum-metrology protocols. Maximally entangled probe states are very sensitive, but extremely fragile; unentangled probe states in contrast are less sensitive, but very robust. A good quantum-metrology protocol entails finding a delicate balance between the diaphanous beauty of quantum mechanics in ideal conditions, and the nasty beast of real-world imperfections. ❒

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SUPERCONDUCTIVITY

Heike's heritage

A century ago, Heike Kamerlingh Onnes discovered superconductivity. And yet, despite the conventional superconductors being understood, the list of unconventional superconductors is growing — for which unconventional theories may be required.

Dirk van der Marel and Mark Golden

On 8 April 1911, Heike Kamerlingh Onnes and his collaborators at the University of Leiden discovered the amazing phenomenon of dissipationless flow of electrical current in mercury. Forty-five years passed before John Bardeen, Leon Cooper and Robert Schrieffer explained what has become known as superconductivity as arising from the organization of the conduction electrons into pairs. Owing to their bosonic nature, a large number of these Cooper pairs can occupy the same macroscopic quantum state, enabling materials such as NbTi or Nb_3Sn to support huge electrical current densities. It also makes superconductivity a quantum phenomenon on a scale as big as the length of the conducting wire, operating over many miles in a commercial magnetic resonance imaging magnet.

Tempted by the unique possibility of an exact match in time and place, a workshop '100th Anniversary of Superconductivity: Hot Topics and Future Directions' was held from 4–8 April 2011 at the Lorentz Center at the University of Leiden[1]. The mission was not only to mark this centenary but also to capture the current opinion as regards unconventional superconductivity and to identify future directions. To do this, the workshop brought together a select band of experimentalists and theoreticians for a lively and fascinating exchange of views on experimental data, theories and opinions covering a wide variety of superconducting systems.

A characteristic of the field is that the family of superconducting materials is expanding at a steady rate, now containing numerous families of materials, with the highest critical temperatures having reached half of room temperature (in Kelvin). The topics covered at the workshop ranged from organic compounds, heavy fermions, iron-based oxides, cuprates, non-centrosymmetric materials and field-effect superconductivity, as well as string theory applied to superconductivity.

An obvious challenge is to provide a unifying framework for the understanding of these diverse materials systems[2–9]. A recurring theme throughout the workshop was that on varying pressure, magnetic field or some material parameter, a quantum phase transition is often observed between the superconducting phase and a magnetically ordered phase[10–12]. This connection suggests that quantum phase transitions could play an important role in the mechanism of superconductivity in a number of the relevant materials families. The questions as to which classes of superconductors this applies, and to what extent a revision of BCS theory is needed, were at the centre of discussions at the workshop[13–15].

One of the refrains of the workshop was the need to understand the 'normal' conducting state, of which the superconducting state is an instability. That practically all unconventional superconductors possess anomalous or strange normal states could be linked to the effects of a funnel of quantum critical matter extending above the critical point, as the relevant control parameter is tuned close to optimal T_c, the superconducting transition temperature. However, the nature of the quantum critical order differs from one material to another. For example, in several of the heavy fermion superconductors it is a spin-density wave. In the cuprates, there are a wide variety of suspects, but an increasing number of indications are found that, as well as charge/spin stripes, anti-ferromagnetism, inhomogeneities and lattice distortions, a time-reversal symmetry breaking order[14] occurs, which leaves translational symmetry intact, with a quantum phase transition to a Fermi liquid close to optimal doping.

The potentially central role of quantum criticality in strongly interacting fermionic systems has also inspired novel theoretical approaches, and one session dealt with holographic superconductivity, anti-de Sitter/conformal field theory correspondence and the connection to string theory. Although at first glance such ideas may seem remote from the daily affairs in a solid-state physics laboratory, they do represent novel doorways towards understanding correlated matter, and can be expected to ultimately play a role in the quest for materials with interesting and useful electronic properties.

What was certainly clear from the workshop was the great level of maturity that numerous experimental techniques have achieved, often as a direct result of the competitiveness and vigour of the superconductivity field itself. Not only have the samples themselves improved tremendously in the older materials families, but also spectroscopic probes such as photoemission, scanning tunnelling spectroscopy, sophisticated optical techniques and neutron scattering are now as firmly part of the experimental repertoire as are transport and thermodynamic experiments, the latter enjoying a valuable renaissance due to the great recent leaps in high-magnetic-field technology.

That all these refined experiments, together with their theoretical counterparts stretching right to the borders of string theory and cosmology, will continue to play a defining role in the field was one of the things all delegates agreed on. New synthetic avenues, such as field-effect doping in ionic liquids[16], were seen by many as fascinating pathways to as-yet unexplored territory: for example for the creation of 'designer' two-dimensional superconductors with tunable carrier densities[17].

All in all, it was a highly stimulating and enjoyable week, with discussions — although sometimes high in volume and passion — always conducted in the forgiving manner of an extended family gathering to discuss, disagree and dream at their celebration of a remarkable milestone in physics. ❐

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